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ABSTRACT

The Laboratory Structure and Task Analysis Inventory (LAI) is an instrument designed to facilitate the analysis of laboratory investigations in secondary school science. It yields a quantitative picture of the kinds of activities required of a student in performing laboratory investigations. The report includes guidelines for the use of the instrument, some descriptive information, and a very brief review of the relevant literature. (Author/BB)

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The Laboratory Structure and Task Analysis Inventory (LAI): A Users' Handbook

by

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THE LABORATORY STRUCTURE AND TASK ANALYSIS INVENTORY (LAI):

A User's Handbook

Table of Contents

	Page
Introduction	1
Inquiry and Science Teaching - An Overview	2
The Role of The Laboratory	4
The Instrument	7
Ground Rules	12
Category Definitions and Examples	16
Instrument Description and Use	27
Development	28
Reliability	29
Interpretation of Results	30
Applications	31
References	32

THE LABORATORY STRUCTURE AND TASK ANALYSIS INVENTORY (LAI):

A Users' Handbook

technical report 14

INTRODUCTION

The Laboratory Structure and Task Analysis Inventory (LAI) presented in this Technical Report is an instrument designed to facilitate the analysis of laboratory investigations in secondary school science. It yields a quantitative picture of the kinds of activities required of a student in performing laboratory investigations.

The Technical Report includes guidelines for the use of the instrument, some descriptive information, and a very brief review of the relevant literature.

> Along with the rapid and widespread change in the secondary school science curricula has come the need for thorough evaluation of new materials in terms of their objectives. Unfortunately, independent evaluative efforts have lagged behind widespread adoption of the materials. This is particularly true of evaluation in terms of an objective cited almost without exception in these new materials--that of bringing students to some understanding of the nature of scientific inquiry (Herron, 1971, p. 171).

> Certainly laboratory work is not as efficient and effective a mode of instruction as it might be, and it is high time we take a hard look, with a fresh perspective, at learning in the laboratory (Anderson, 1976, p. vi).

INQUIRY AND SCIENCE TEACHING

An Overview

Many science curricula, instructional materials, and methods textbooks have identified inquiry as very different activities and strategies with very little agreement as to what constitutes inquiry and what does not (Wilson and Koran, 1976). Herron (1971) attributes the lack of evaluation of inquiry in new curriculum materials to the variety and obscurity of inquiry strategies and to the lack of a sound conception of the nature of scientific inquiry.

> The lack of clarity both of the literature dealing with the science curriculum and of the materials themselves raises the further question of what meaning, if any, such a phrase as "scientific enquiry" has for teachers who are expected to utilize the new materials (Herron, 1971, p. 171).

Different treatments of the subject of inquiry are defensible. Some differences among accounts of inquiry originate in differences in the way scientists have approached and resolved conceptual problems, "...other diversities arise from differences in philosophic principles and methods which dictate different ways of describing the scientific enterprise" (Herron, 1971, p. 173).

Besides being referred to generally as characterizing the scientific enterprise, inquiry is often described as the set of specific processes or skills used by scientists in their work. In Science: A Process Approach, (AAAS, 1973) the "basic" processes are described as: observing, using space/time relationships, classifying, using numbers, measuring, communicating, predicting, and inferring; and the "integrated" processes are described as: controlling variables, interpreting data, formulating hypotheses, defining operationally, and experimenting. Anderson (1976), Renner

and Stafford (1972), and Schwab (1962), among others, delineate somewhat similar versions of these scientific processes.

The rationale for using specific methods or techniques such as inquiry in the classroom is based to a great extent upon one's beliefs concerning the goals and objectives for science education and the purpose of teaching science in general. The view that science is best taught by fostering the behaviors "inquiry" and "discovery" has been challenged by Ausubel (1968). Certainly an all-or-none position regarding the use of "discovery" is warranted by neither logic nor evidence (Tisher, 1972). However, some of the main reasons, purposes or goals associated with the teaching of science as inquiry can be grouped into the following three broad categories: 1) To teach processes and skills which can then be transferred to other disciplines and other activities in life; 2) To develop scientific literacy, develop an understanding of science and scientists, and to reflect the nature of science (although Newton, 1968, would argue that the inquiry approach gives a "false" image of the nature of science); 3) To emphasize development of critical thinking abilities, problem-solving abilities, independent learning, and to facilitate the "formal" phase of intellectual development.

The Role of the Laboratory

With the emergence of the so-called processes of science as major goals in science curricula came the question of what methods or techniques could best faciliate the achievement of this goal. Attention became focused on the science laboratory as one important vehicle for bringing students to an understanding of the processes of scientific inquiry.

> ..., with the shift of emphasis from the acquisition of knowledge to other objectives which stress the processes of science, the laboratory acquired a central role, not as a means for demonstration and confirmation but rather as the core of the learning process (Shulman and Tamir, 1973, p. 1119).

The National Science Teachers Association (NSTA, 1978) recommended that in order for the teaching of science and science courses in the schools to reflect the experimental nature of science, "inquiry-based" laboratory activities should be included in all courses at all levels", and "equipment and supplies essential to an inquiry-based, activity-oriented approach must be provided by the schools" (p. 32).

Many educators (Schwab, 1962; Ausubel, 1968; Hurd, 1969; Tamir, 1977; Lunetta and Tamir, 1978) express the view that the major uniqueness of the laboratory lies in providing students with opportunities to engage themselves in the process of investigation and inquiry. This is in contrast to using the laboratory primarily as a place to illustrate, demonstrate, or verify known concepts and laws. As pointed out by Lucas (1971), students personally practicing inquiry can understand how scientists work, and also learn how to acquire new knowledge by themselves. Schwab (1962) believes that one of the major functions of the laboratory in a curriculum that emphasizes inquiry is "to provide a tangible experience in some of the problems dealt with and of the difficulty of acquiring data."

Activity in the laboratory, however, does not insure attainment of inquiry objectives.

With the view that laboratory work should be seen as a means of integrating science concepts and inquiry processes, the newer curriculum studies (of the 1960's) sponsored by the National Science Foundation placed

more emphasis on the laboratory as a place where the many aspects of s scientific inquiry are introduced, developed, and practiced. The goals for laboratory instruction in the modern science course "focus upon the inquiry, discovery, process, or methodological phase of science and upon its intellectual components" (Hurd, p. 112).

As was pointed out by Ramsey and Howe (1969) inquiry methods and methods designed to have students working with the processes of science are likely to produce different outcomes than are conventional procedures. Yet, more sensitive evaluation instruments need to be developed that will provide better information on student growth and competency in the development of inquiry and problem solving skills. Research on ways the new materials and methods may be used and upon the effects of these procedures seems essential.

The laboratory manual can be a key to how effectively the laboratory can be used:

> While the laboratory manual is only one of many ingredients in a science classroom, it plays a major role for most teachers and students in defining goals and procedures for laboratory activities. It also helps to focus observations and development of inferences, explanations, and other activities in a laboratory investigation" (Lunetta and Tamir, 1978, p. 3).

There are few instruments designed specifically to test the quality of written laboratory manuals (Shulman and Tamir, 1973), and the Laboratory Task Analysis Inventory (LAI) has been developed in response to this need.

THE INSTRUMENT

LABORATORY STRUCTURE AND TASK ANALYSIS INVENTORY

By Pinchas Tamir and Vincent Lunetta with the assistance of Shimshon Novick and Marlene Fuhrman

AUTHOR _____
TITLE _____
EDITION OR YEAR _____
PUBLISHER _____
NAME OF EVALUATOR _____

Organisational Categories \ Investigation Number										
A. STRUCTURE										
a.1 High-structure										
a.2 Low-structure, open										
a.3 Inductive approach										
a.4 Deductive approach										
B. RELATION TO TEXT										
b.1 Precedes text										
b.2 Follows text										
b.3 Integrated with text										
C. COOPERATIVE MODE										
c.1 Students work on a common task and pool results										
c.2 Students work on different tasks and pool results										
c.3 Postlab discussion required										
D. LABORATORY SIMULATIONS										
d.1 Student performs "dry lab" - data given by authors										
d.2 Student performs task that simulates or models phenomena										
d.3 Student performs experiment by gathering data from a secondary source										
d.4 Student performs simulated experiment by interacting with a program										

Laboratory Structure and Task Analysis Inventory

Tamir, Lunetta, Novick, Fuhrman

Task Categories \ Investigation Number					
1.0 PLANNING & DESIGN					
1.1 Formulates a question or defines problem to be investigated					
1.2 Predicts experimental result					
1.3 Formulates hypothesis to be tested in this investigation					
1.4 Designs observation OT measurement procedure					
1.5 Designs experiment					
2.0 PERFORMANCE					
2.1a Carries out qualitative observation					
2.1b Carries out quantitative observation or measurement					
2.2 Manipulates apparatus; develops technique					
2.3 Records result, describes observation					
2.4 Performs numeric calculation					
2.5 Interprets, explains or makes a decision about experimental technique					
2.6 Works according to own design					
3.0 ANALYSIS & INTERPRETATION					
3.1a Transforms result into standard form (other than graphs)					
3.1b Graphs data					
3.2a Determines qualitative relationship					
3.2b Determines quantitative relationship					
3.3 Determines accuracy of experimental data					
3.4 Defines or discusses variables, limitations/ or assumptions that underly the experiment					
3.5 Formulates or proposes a generalization or model					
3.6 Explains a relationship					
3.7 Formulates new questions or defines problem based upon result of investigation					
4.0 APPLICATION					
4.1 Predicts based upon result of this investigation					
4.2 Formulates hypothesis based upon results of this investigation					
4.3 Applies experimental technique to new prob-					

LABORATORY STRUCTURE AND TASK ANALYSIS INVENTORY (Tamir, Lunetta, Novick, Fuhrman)

Task Categories \ Investigation Number	
1.0 PLANNING & DESIGN	
1.1 Formulates a question or defines problem to be investigated	
1.2 Predicts experimental result	
1.3 Formulates hypothesis to be tested in this investigation	
1.4 Designs observation or measurement procedure	
1.5 Designs experiment	
2.0 PERFORMANCE	
2.1a Carries out qualitative observation	
2.1b Carries out quantitative observation or measurement	
2.2 Manipulates apparatus; develops technique	
2.3 Records result, describes observation	
2.4 Performs numeric calculation	
2.5 Interprets, explains or makes a decision about experimental technique	
2.6 Works according to own design	

Laboratory Structure and Task Analysis Inventory (Tamir, Lunetta, Novick, Fuhrmann)

3.0 ANALYSIS & INTERPRETATION	
3.1a Transforms result into standard form (other than graphs)	
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3.3 Determines accuracy of experimental data	
3.4 Defines or discusses limitations and/or assumptions that underly the experiment	
3.5 Formulates or proposes a generalization or model	
3.6 Explains a relationship	
3.7 Formulates new questions or defines problem based upon result of investigation	
4.0 APPLICATION	
4.1 Predicts based upon result of this investigation	
4.2 Formulates hypothesis based upon results of this investigation	
4.3 Applies experimental technique to new problem or variable	

GROUND RULES

GENERAL

G-1. Refer to neither the textbook nor the teacher's guide for purposes of classifying investigations. However, if student laboratory instructions and the text are incorporated in one volume, or if the text specifies when a laboratory investigation is to be done, this information should be used in the laboratory organization categories (A-D) only.

G-2. All required investigations should be analyzed. Optional, supplemental or excursion investigations may be entered in columns labeled "opt." These data may or may not be included in the course analysis, depending upon whether minimum or maximum potential is being evaluated.

G-3. The decision as to how to categorize should take into account the context of the situation; frequently terms are not used with precision in textbooks and laboratory handbooks. For example, an investigation may use the term "hypothesis" in the sense of prediction. It may ask, "What do you conclude?", when the intent is that the student form a generalization. Care should be taken when differentiating between qualitative and quantitative inferences as this is not always explicitly stated. Definitions and examples for the various categories are provided to aid in making the necessary discriminations.

ORGANIZATIONAL CATEGORIES

O-1. The overall investigation, not each task, is what is considered for coding for these categories (A-D). Thus the maximum number of checks in any one cell for a given investigation would be one.

O-2. Category A (Structure) and Category B (Relation to Text) should be coded for all investigations; the coding of Category C and Category D will depend on the nature of the individual investigations.

O-3. A check should be placed in the appropriate cell if the investigation, for the most part, fits the category. For example, an investigation which is mainly (although no entirely) high-structure should be checked in category a.1.

O-4. It is possible that a given laboratory investigation adopts an inductive approach in one section and a deductive approach in another; when this occurs check both cells (a.3 and a.4) for the particular investigation.

O-5. While category b.1 (Precedes Text) and b.2 (Follows Text) are mutually exclusive, category b.3 (Integrated with Text) may be checked with either category b.1 or b.2.

TASK CATEGORIES

T-1. Each task, not each statement in the laboratory investigation, should be coded; a group of statements may be interpreted as one task.

T-2. If a statement demands discreet activities in more than one task category, all such task cells will be checked. For example, one statement may mention observing as well as graphing.

T-3. If a statement appears to overlap task cells, the check is made in the task cell which requires the highest level of thought or action on the part of the student.

T-4. A check should be placed in the appropriate task cell each time such a task occurs in the investigation. (Thus a task number will frequently be checked more than once for a given investigation.) (An alternative method is to check the appropriate task cell only once if a task occurs in the investigation.)

T-5. When carrying out an analysis, checks may be used; however, it is suggested that statements in the investigation be consecutively numbered and the statement numbers placed in the appropriate task cell(s). This latter procedure allows for rechecking the analysis.

T-6. In order to summarize the data after completing an investigation, transfer the total number of checks or statement numbers to a new summary analysis sheet.

T-7. Rhetorical questions (which do not require an action or answer on the part of the student) are not coded.

T-8. To indicate whether tasks are required or optional, a second adjacent column should be used to check tasks in optional sections of each investigation.

CATEGORY DEFINITIONS AND EXAMPLES

Definitions and Examples

CATEGORY AND DEFINITION	EXAMPLES[1]
a.1 High-structure. Investigation in which the student is explicitly directed in all aspects of the experiment.	C_1: Investigation #6-5, "A Quantitative Investigation of the Reaction of a Metal with Hydrochloric Acid" P_2: Experiment #5, "A Seventeenth Century Experiment"
a.2 Low-structure, open. These investigations may make an initial suggestion or statement but otherwise the design and extent of the experiment is, for the most part, left to the student.	B_2: Page 1, "Hoppers and Singers" B_2: Page 111, "Crusty Creatures"
a.3 Inductive approach. The investigation involves developing generalizations from data or from individual cases.	C_1: Investigation #5-6, "The Masses of Equal Volumes of Gases" P_1: Experiment #3, "Refraction" P_1: Experiment #20, "Changes in Velocity with a Constant Force"
a.4 Deductive approach. The investigation involves the testing of phenomena or relationships that have been predicted based upon principles or processes that have previously been stated.	C_1: Experiment #22, "Making Oil and Water Mix" P_1: Experiment #15, "Young's Experiment" P_2: Experiment #8, "Newton's Second Law"
b.1 Precedes text. The laboratory investigation precedes significant discussion of the topic in the text.	
b.2 Follows text. The laboratory investigation follows significant discussion of the topic in the text.	C_1: Investigation #11-2, "Does Light Behave Like a Series of Waves?" P_1: Experiment #13, "Waves from a Point Source" P_2: Experiment #25, "Measuring the Speed of a Bullet"

[1] The examples are taken from commonly used texts and laboratory manuals in Biology, Chemistry, and Physics. See page 26 for complete references.

b.3 Integrated with text.
This category is checked if there are substantial references in the text to the topic of the investigation or if the narrative in the investigation refers to the text. Note that while b.1 and b.2 are mutually exclusive, b.3 may be checked with either category b.1 or b.2.

P_2: Experiment #5, "A Seventeenth Century Experiment"
P_2: Experiment #43, "The Photoelectric Effect"

c.1 Students work on a common task and pool results.
See Rule i-1; in order for this cell to be checked, it should be clear from the laboratory investigation being analyzed that students are to pool their results of the task.

P_1: If all the coils used by your class are the same, pool all the class data in a histogram and from that determine the best value for the slope of the graph. (42)[2]

c.2 Students work on different tasks and pool results.
See Rule i-1; in order for this cell to be checked, it should be clear from the investigation that students are to pool their results of the various tasks.

B_1: Each group will be assigned specific temperature conditions with which to work....When all the class data are on the board, prepare a data table... using the assigned temperatures and the class data. (6-3)

c.3 Postlab discussion required.
Members of the class are explicitly directed to further process or compare data or results through group discussion after gathering experimental data.

C_1: You may fill in this list during the post-lab discussion of the experiment. (1-3)
P_1: How does the circulation around your polygon compare with that of your classmates using different polygons? (45)

d.1 Student performs "dry lab" - data given by authors.
The data the student processes is printed in the laboratory text.

P_1: In Table 1 are the results of an experiment. You are asked to present and analyze these results in a form which will enable you to predict the outcome of similar experiments. (1)

d.2 Student performs task that simulates or models the phenomenon being discussed.

B_1: In this inquiry...your model of a cell will substitute cellophane for the cell membrane. (6-1)
C_1: Using styrofoam spheres as building blocks, you will study some of the ways in which typical metallic crystals can be formed. (17-5)

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2. The numbers in parentheses refer to the specific laboratory investigation or page where the example was found.

d.3 Student performs experiment by gathering data from a secondary source.
The data the student works with is given via slides, pictures, film loops, etc.

P_2: You can use distance units measured directly from the photograph . . . (22)

d.4 Student performs simulated experiment by interacting with a program.
The student performs the experiment and gathers data by interacting with a computer or some other programmed source.

The student...

1.1 Formulates question or defines problem to be investigated.
The experimental problem is not stated or defined explicitly and the student is required to come up with his/her own formulation of the problem.

B_2: The questions and problems which you decide to investigate will determine the kinds of experiences you have...(p.1)

B_2: You have probably not thought about them as something to study in a biology class, but there are many things to discover about them. What would you like to learn about these "Crusty Creatures?" (p.111)

1.2 Predicts experimental result.
The student is asked to predict an experimental result based on his/her previous knowledge; a prediction is a logical outcome and in this respect differs from hypothesis formulation, which implies alternative explanations.

B_1: If the cells are in water that has the same concentration of salts, no special problems occur. But what do you think will happen if you place the cells in a higher concentration of salt solution? Observe the effect on the cells as the salt water moves over the leaf. (6-2)

C_1: If...light has wave-like characteristics,...what would you expect to observe where two wave crests came together? (11-2)

P_1: Before making any runs, what do you predict (qualitatively) about the total kinetic energy after the collision? (31)

The student...

1.3 Formulates hypothesis to be tested in this investigation.
The student is asked (explicitly or implicitly) to formulate a hypothesis, to offer a tentative explanation, or to propose a relationship. The explanation or relationship must be tested experimentally in order to decide among competing hypotheses. Hypotheses are commonly sought before engaging in laboratory activity, but students may be asked to generate them at many points in a laboratory investigation.

- B_1: How do you think the concentration of each of the 3 fluids compares with that of the fluids in the cells of the frogs? (13-1)
- B_1: By carefully observing and examining Paramecium you are to form a series of hypotheses regarding the functions of the structures that you are able to observe in the animal. Test these hypotheses... (9-2 thru 9-5)
- B_2: Where did the living things you found in your culture come from? (Were they in the water to begin with? Or did they come from the material you put in the water?) (p.58)

1.4 Designs observation, measurement or calculation procedure.
The student must be asked to design and carry out or describe procedure for part of a laboratory investigation; if asked to develop the overall design of the investigation, then category 1.5 is more applicable and should be checked instead.

- P_1: Use your knowledge of living processes and make what observations you can that will throw light on your hypotheses. (9-2)
- B_1: What control would you suggest for this inquiry? (13-1)
- C_1: What gas evolved when....If you are not sure, how would you test the gas to establish its identity? (16-12)
- P_1: It is more difficult to investigate experimentally the dependence of the centripetal force on the radius... suggest a way of doing this... (24)

1.5 Designs experiment.
This category is at a higher level than category 1.4 and is more encompassing. The student is asked to design an entire experimental procedure, not just part of it. The student need not be asked to actually perform the experiment in order for this category to be checked.

- B_1: Devise an experiment to test tolerance of vinegar eels to pH changes. (16-1)
- C_1: Devise an experiment to measure the heat effect for the phase change... for some suitable substance. (4-8)
- P: Describe a similar experiment that would compare the masses of 2 iron objects to the magnetic forces exerted on them by a large magnet. (9)

2.1a Carries out qualitative observation.
The student does what can be termed observation.

- B_1: Observe it in a drop of 5% solution with the microscope. (6-2)
- B_1: How do the abdomens compare in shape? (27-1)
- C_1: Note the temperature of the water as you stir and continue to observe the temperature... (4-8)

The student...

2.1b Carries out quatitative observation or measurement.
This category is checked only when the observation involves counting or numeric measurement.

B_1: How many were in the F_1 generation? (27-2)
C_1: Determine the mass of a piece of metal to the nearest gram. (3-5)
P_1: First, measure the period of the balance alone by measuring the time for as many vibrations as you can count. (22)
P_1: How many times per second was the capacitor charged and discharged? (39)

2.2 Manipulates apparatus: develops technique.
When a statement specifies or implies the use of a specific laboratory technique, this category applies.

B_1: Run iodine under the cover glass in the following way. (3-2)
B_1: You can demonstrate the rate of transpiration in plants with a simple piece of equipment, the potometer. (18-3)
C_1: Decant the solution off the silver crystals. (22-17)
P_1: To find the wavelength, "stop" the wave pattern with the stroboscope and...place 2 pencils or rulers parallel to the waves and several wavelengths apart. (10)

2.3 Records result, describes observation.
In order for this category to be marked, it must be stated or strongly implied that the student write something, i.e., record what he/she is doing sometime during the course of the laboratory investigation. The result may be a quantitative or a qualitative observation, or the student may be asked to describe what occurred, what he/she saw, etc. This category should be checked if subsequent treatment of the data clearly requires that it was recorded.

B_1: After your examination..., list as many properties of cork as you have been able to observe. (3-1)
C_1: Record your specific heat for each metal. (3-5)
P_1: Describe, qualitatively, the properties of the force that caused... (22)
P_2: Keep a record of the azimuth and the time of observation. (1)

2.4 Performs numeric calculation.
The student is directed to calculate a numerical quantity from data obtained in the laboratory investigation.

B_1: What is the total temperature change that occurred in the reaction chamber? (4-2)
B_1: What is the dilution of the source material in tube 1? (23-1)
C_1: From your measurements of mass and volume find the density of the solid. (4-4)
P_1: From the tapes and the masses... compute the change in momentum of the cart. (30)

The student...

2.5 Interprets, explains or makes a decision about experimental technique. The student is required to make an analytical or critical statement concerning a technique used in the laboratory investigation.

- B_1: How will you know when the reaction is completed? (4-1)
- C_1: Why was it necessary to cool the evaporating dish completely before the final determination of its mass? (7-8)
- P_1: When should you test for it (leakage), during the run or at the end? (36)
- P_1: Why was it necessary to keep the rest of the wire and iron objects far away from the compass? (44)

2.6 Works according to own design. In order for this category to be marked, the student must be required during the course of the laboratory investigation to actually perform the experiment (category 1.5) or the procedure (category 1.4) that he/she designed.

- B_1: While these two tubes are being brought to the water bath temperature, design a control for this inquiry.... How does the control you designed indicate whether only the diastase was responsible for the disappearance of the starch? (6-3)
- P_2: Can you...describe an independent method for finding v...try it, and explain any differences between the two v values. (25)

3.1a Transforms result into standard form (other than graphs). Standard form refers to a standard ordering process, such as generating a table, a classification scheme, a diagram, a sketch (to the exclusion of diagrams or sketches of apparatus); included also are chemical equations when the identity of reactants and products is given by the laboratory text rather than determined experiementally. This category is not checked if students are merely directed to fill in table, without exercising judgement.

- B_1: Draw...a simplified outline of Paramecium as you see its appearance through the microscope. Add within the outline all the parts of the animal that you observe. (9-1)
- C_1: When an alcohol reacted with concentrated HCl, an alkyl chloride having the general formula RCl was formed. Write an equation to show this reaction. (16-12)
- P_2: In this experiment...you observe very simple motion, and make a photo record of it. You measure...and record your data in tables... (4)

3.1b Graphs data. This category is checked only if the student is required to graph quantitative measurements (whether previously tabulated or not). Vector diagrams drawn to scale are also included in this category.

- B_1: Make a graph of the relation of this movement to time. (18-3)
- C_1: Prepare a bar graph for your data. Plot your results on the graph. (12-3)
- P_1: Plot the diameter of the circle as a function of the distance. (5)

The student...

3.2a Determines qualitative relationship.
The student is required (explicitly or implicitly) to make an inference (arrive at a decision or opinion by reasoning from evidence), or draw a conclusion that does not involve mathematical manipulation.

B_i: What do changes in each tube indicate? (17-4)
C_i: Is there any relationship between the molar masses of Mg and Ca and the reaction rates for the reaction between these elements and water? (8-2)
C_i: Do you find any relationship between the spacing of the points you have marked on your drawings and the observations you have made in the experiment? (11-2)
C_i: What regularities appear on your graph? (13-7)

3.2b Determines quantitative relationship.
This category is checked when the student is required to formulate the inference or conclusion as a quantitative relationship that involves mathematical manipulation. The determination of an empirical or molecular formula from experimental data is a task in this category. Construction of a chemical equation based on experimental identification of products is a conclusion.

C_i: Try to find some constant numerical relationship among the equilibrium concentrations of the ions... (22-14)
P_i: What can you say about the ratio of force to acceleration in this experiment? (21)
P_i: Find the quantitative relationship between the quantity of matter...and the period of vibration. (22)
P_i: How is this frequency (of rotation of the stroboscope) related to that of the waves? (10)

3.3 Determines accuracy of experimental data.
This category is checked when the student is required to determine a numeric value that describes the amount of error. Examples include determining percentage error, estimating how much error is inherent in data, determining the uncertainty of measurements or results, or comparison with a standard.

C_i: How close were your measurements of the density...to the known density? (4-4)
C_i: What percentage error would you expect to have in trying to measure 1.0 ml of water to the nearest 0.1 ml? (4-4)
C_i: Estimate the limits of error on the mole ratio. (9-10)
P_i: Using all the information you have, what is the accuracy of your determination of h (Planck's constant)? (47)

The student...

3.4 Defines or discusses variables, limitations or assumptions that underly the experiment.
This category is checked only when the student must respond to a direction or a question by defining or discussing variables, limitations or assumptions that underly the observation or the interpretation of experimental data. It is not checked when a variable, limitation or assumption is merely specified or implied in the text.

C: Which of these conditions (in the laboratory) may have had an important effect on the way in which the candle burned? (1-3)
C: Where...might there be sources of error in this experiment? (3-5)
P: What assumptions have you made in all of your predictions about the mass of the spring on the period? (25)

3.5 Formulates or proposes a generalization or model.
This is a more global requirement than category 3.2, in that it goes beyond the data and specific instance at hand and asks the student to generalize to or about other instances outside the immediate laboratory results. In this respect, it differs from drawing conclusions that pertain only to the phenomena sampled in the laboratory.

B: On the basis of your inquiries into the nature of cells, prepare a statement about your investigation of the cell theory. (3-3)
C: From your consideration of the models constructed, what can you deduce about the relationship between the radius ratio of ions and the coordination number in crystals? (17-5)
C: What generalizations can you make concerning the effect of varying the concentration on the time of the reaction? (21-3)
P: What simple mathematical relation do you think best describes the refraction of light? (1)
P: What do you conclude about the acceleration produced by a constant force? (20)

3.6 Explains a relationship.
This category requires making relationships clear and intelligible. The explanation involves a discussion of relationships that fit the results of the experiment. It differs from categories 4.1 and 4.2 which ask the student to make predictions or propose alternate hypotheses based upon laboratory data. Comparing with a model (qualitatively or quantitatively) also belongs to this category.

B: What explanations can you give for the different cork cell shapes in your preparation? (3-1)

C: Explain why such a constant numerical relationship might exist. (21-3)
P: Do your observations support Newton's Second Law? Explain. (8)
P: Why is there such a large difference in kinetic energy? (25)

The student...

.7 Formulates new questions or defines problem based upon result of investigation.
The student is directed to come up with his/her own formulation of new questions or a problem for further investigation as a result of the laboratory work.

B_2: Have you found out all you want to know? If not, continue on with anything you wish to investigate. (p.11)
C_1: As a result of your observations, make a list of unanswered questions that this experiment has raised in your mind. (1-3)

.1 Predicts based upon result of this investigation.
The student is required to make a prediction on the basis of his/her findings in the experiment or on the basis of previous knowledge combined with the findings. The prediction does not require testing for validation--thus it differs from category 1.3 (formulates hypothesis to be tested) and category 1.2 (predicts experimental result). Here too, a prediction can be made by logical deduction from what has been learned in the investigation.

B_1: If a glycerinated muscle fiber is exposed to salts as before and then ATP is added...whay will happen? (6-4)
C_1: Based on its molar mass, how would you expect cesium to react with water? (8-2)
P_1: Can you predict how light will bend when it goes obliquely through a block of glass with parallel sides?(1)

.2 Formulates hypothesis based upon results of this investigation.
The student is required to formulate an hypothesis on the basis of his/her findings in the experiment, or on the basis of previous knowledge combined with the findings. An hypothesis offers a tentative explanation or proposes a relationship. This category may be checked even if the experimental test is not required. Hypothesis formulation implies alternatives.

B_1: On the basis of your observations, what hypothesis can you make about the possible functions of... (3-1)
B_1: Examine one of these cells under high power. Form a hypothesis to account for the location of the chloroplasts within the cell. (3-2)
C_1: Try to propose a theory that would explain how heat is transferred from a hot piece of metal to cool water.(3-5)
C_1: Why do you think different substances have different densities? (4-4)

4.3 Applies experimental technique to new problem or variable.
The key word here is "technique", as opposed to the use of knowledge and/or findings in the predicting sense. The technique refers to one which the student has learned or used in the laboratory investigation. This category may be found frequently in optional sections (usually preceded by qualifiers such as "if time permits"). If this is the case, check the category in an adjacent column Rule T-8. This category should also be checked if the student is required to explain how to apply the technique but does not carry it out.

B_1: Can these be tested in the manner used...? If so, design an experiment, ...to test the effects of another environmental variable in this fashion.(6-3)
C_1: Determine the heat of combustion of a pure substance, such as stearic acid, and then compare your results with data that you find in the literature. (4-8)
P_1: Is the path...the same when its direction is reversed? Investigate this...(1)
P_2: Measure d/t^2 for several different sizes of balls, all rolling down the same distance down a plane of the same inclination. (5)

Codes and Corresponding References

B: Biological Sciences Curriculum Study. Biological Science: An Inquiry into Life. Third Edition. New York: Harcourt Brace Jovanovich, Inc., 1973.

B: Biological Sciences Curriculum Study. Biological Science: Invitations to Discovery. New York: Holt, Rinehart, and Winston, 1975.

C: Cotton, F. A., et.al. Chemistry - An Investigative Approach. Second Revised Edition. Boston: Houghton Mifflin Company, 1973.

C: DeVoe, Howard. IAC - Communities of Molecules. New York: Harper & Roe, Publishers, 1973.

P: Haber-Schaim, U., et.al. PSSC Physics Laboratory Guide. Third Edition. Lexington, Massachusetts: D. C. Heath and Company, 1971.

P: Rutherford, F. J., et.al. (Directors, Harvard Project Physics). The Project Physics Course Handbook. New York: Holt, Rinehart, and Winston, Inc., 1970.

DESCRIPTION AND USE

The LAI has two primary sections. The first section, labeled Organizational Categories, consists of four sub-sections: Structure; Relation to Text; Cooperative Mode; and Laboratory Simulations. These sub-sections include a total of 14 categories. The section provides an overview of the structure and approach of a laboratory investigation. The second section, labeled Task Categories, consists of the inquiry categories upon which the task analysis is based. This part also consists of four sub-sections: Planning and Design; Performance; Analysis and Interpretation; and Application. These sub-sections have four to seven categories per section. Some of these categories are sub-divided into a qualitative and a quantitative component, giving a total of 24 categories in the present version of the instrument.

The LAI in its present form is comprehensive, intended for use with curricula for most science disciplines. It can be converted to a shorter version if applied to only one specific discipline. Categories can be further sub-divided or combined, depending on the goals of the user.

Development

The LAI was developed and first reported by Tamir and Lunetta (1977) for the purpose of analyzing printed laboratory activities required of students in biological science curricula. At that time there were a total of twenty categories in the scheme, many of which were drawn from publicational and goals statements of the Biological Science Curriculum Study (BSCS). Subsequently, new categories were added and some existing ones modified in order to use the scheme with physics curricula (PSSC and Project

Physics). Results of these analyses are reported in Lunetta and Tamir (1978). The instrument was then modified further and used in an analysis of chemistry curricula (February 1978). At that time, ground rules for u use of the instrument were delineated to insure a standardized method of coding, and definitions and examples of categories taken from biology, chemistry and physics curricula were prepared.

Reliability

According to Brown and Webb (1968) the reliability of a measurement "is the statement which represents the various sources of error in the repeated measurement of a single phenomenon or the consistency in which an individual performs the same task over a period of time" (p. 37).

Six individuals, three of whom were the developers, were involved in coding the same laboratory investigations in order to obtain a quantitative measure of the reliability. Each of the coder's scores was compared to a master code for each of the investigations, and an agreement index was computed using the Scott Coefficient, π (Flanders, 1965; also cited in Penick, 1973), where

$$\pi = \frac{(Po - Pe)}{(100 - Pe)}$$

In this formula, Po is the percent agreement found by calculating the total percent error between two coders and subtracting from 100. Pe is the percent agreement expected by chance and is found by squaring the proportions of error between coders in each category, dividing the squares by 100, and summing over all categories. Thus, the value of π is the amount that two coders exceed chance agreement divided by the amount that perfect

agreement exceeds chance. In the analysis of chemistry laboratory investigations, the value of the Scott Coefficient ranged from 0.57 to 0.81, with an overall average of 0.71, indicating fairly high inter-coder agreement (Fuhrman, 1978, pp. 49-52).

Interpretation of Results

When comparisons between categories and between different curricula are to be the data must be interpreted with care and caution. An activity in one category, e.g., making an observation or measurement, is not equivalent to an activity in another category such as formulating a hypothesis. Furthermore, while each statement or group of statements is coded (Ground Rules), the categories reauiring "Performance" activities on the part of students in many investigations necessarily contain many more specific instructions and activities than do other categories such as formulating an hypothesis or explaining a relationship. Whether or not the particular activity occurs in a laboratory investigation may well be a more meaningful measure than the frequency of "checks" (activities) recorded per category.

In analysis which did involve the frequency of activities in each category, the following indices have been of interest in presenting data.

> The number of checks in Performance section 2B (2.5-2.6) divided by the number of checks in Performance section 2A (2.1-2.4) forming an index of behaviors requiring initiative on the part of the student to those behaviors directed by explicit instructions.
>
> The number of checks in <u>interpreting</u> activities 3B (3.4-3.7) divided by the number of checks in <u>observational</u> activities 3A (3.1-3.3).
>
> The number of checks in "higher order" activities (sections 1.1 to 1.5, 2.5, 3.4 to 3.7, 4.1 to 4.3) divided by the number of checks in "lower order" activities (sections 2.1 to 2.4 and 3.1 to 3.3)

Applications

Up to this time the LAI has been used primarily in the analysis of laboratory handbooks of selected science curricula. Base line data will be helpful to teachers, curriculum developers, and researchers over a broader array of contemporary curricula. The LAI should also be of value in other applications.

1. The LAI can be simplified to a form more generally useful for teachers and teaching practice. Interested high school science teachers could use the simplified version of the LAI, and code the laboratory guides they are currently using or those which may be considered for adoption. Comparison of their "subjective" views and the results of coding would provide further insights into the value of the curriculum materials for classroom use and would yield implications for teaching practice.
2. The LAI can be used in preservice teacher education to help prospective teachers better understand the nature of curriculum materials.
3. Studies could be undertaken comparing the LAI analysis of laboratory guides with interaction analysis of students in laboratory-classrooms. Such studies could determine how the published materials are in fact related to student behavior.

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